THE USE OF THREE-DIMENSIONAL ANALYSES OF CLOUD ATTRIBUTES FOR DIABATIC INITIALIZATION OF MESOSCALE MODELS

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1. INTRODUCTION

Diabatic initialization of cloud-resolving forecast models such as MM5, RAMS, ARPS, and WRF allows these models to prognose the future of precipitating cloud systems such as snowstorms and thunderstorms that are present at the initial time. This is a solution to one of the most long-standing problems in NWP: the 1- to 3-h spin-up of cloud systems caused by the use of traditional dry initialization.

Proper initialization of precipitating cloud systems requires simultaneous consideration of the three wind components, temperature, pressure, water vapor, and several kinds of condensate. For example, in saturated updrafts, the local temperature and pressure together specify the (saturation) vapor amount. In cloud-resolving models in which the horizontal and vertical scales of motion are similar, the convective heating rate is firmly tied to the local vertical velocity via the (appropriately scaled) thermo-dynamic energy equation. The same applies to evaporative cooling of rain, snow, etc. Of course, vertical motions are coupled to the horizontal wind field via the mass continuity equation. Failure to satisfy these relationships creates an interesting variety of nonphysical model errors.

Among the many difficulties encountered in this task, perhaps foremost is the fact that the current observation system makes only indirect measure-ments of the particular physical attributes that the models' equation sets require. For example, the models' equations for water substance continuity use mixing ratios, and initializing them requires full three-dimensional specification of the mixing ratios of cloud liquid/ice, rain, snow, and perhaps one or more classes of precipitating ice. However, radars measure electromagnetic reflectivity, so some sort of assumptions about the hydrometeor type and amount are required. That, in turn, is affected by the temperature of the reflectors, but temperature measurements are not provided by radars and must be otherwise obtained. Likewise, satellites measure the radiative properties of clouds, air, and surface; these properties are related only indirectly to the temperature, humidity, and cloud species that the models actually need.

FSL's Local Analysis and Prediction System (LAPS) is intended to deal with these problems.

2. METHOD

The LAPS method for initializing clouds, their associated kinematics, and precipitation proceeds in four steps.

First, a three-dimensional analysis of cloud type and cloud fraction is performed according to Albers et al. (1996), which uses data from a background model, satellites, radars, cloud reports from METARs and voice pilot reports of cloud layers. (This is actually one of the latter tasks of data analysis performed during a LAPS cycle; other tasks generate univariate analyses of temperature, wind, humidity, etc.) The cloud analysis also produces gridded estimates of cloud liquid, cloud ice, and precipitating species such as rain and snow. Updates to the Albers et al. (1996) methods are reported by Birkenheuer et al. (2001).

Second, an estimate of the vertical motions within the analyzed clouds is generated. The following rules are used:

• Cumuliform clouds are fitted with a parabolic vertical velocity profile whose magnitude is linearly dependent on cloud depth (Fig. 1). The magnitude of the parabola is not determined by the results of field studies (Cotton and Anthes 1989, p. 468), which would suggest values as large as 30 m s^{-1}. Instead, practical experience from modeling on 10-km grids indicates that a much smaller value leads to more realistic results. The maximum vertical velocity given by this algorithm will eventually be cast as a function of grid increment.
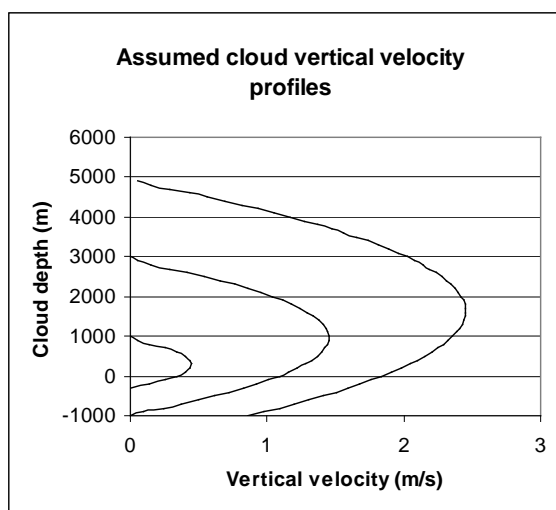

Figure 1. Cloud vertical motion profiles for cumuliform clouds of three heights (1 km, 3 km, and 5 km). Note that the parabolic shape begins slightly below cloud base (i.e., 0 m).

• Stratiform clouds are assigned a small vertical motion (5 cm s^{-1}) held constant through the depth of the cloud. Heymsfield (1975) and Heymsfield (1977) indicate that vertical velocities in cirrus clouds are typically larger than this, sometimes greater than 1 m s^{-1}, but we have not yet seen great sensitivity to this. We should note that we have not yet tested this initialization method in cases with widespread marine stratocumulus, in which it should fail.

• Cloud vertical motion is not assigned in the presence of precipitation, since air parcels containing precipitation might be in downdrafts.

The third step is a variational balancing step, in which the three-dimensional dynamical relationship between mass and momentum is adjusted to force consistency with the diagnosed cloud vertical motions. This is the crucial step that results in good

continuity between the analyzed cloud fields and the forecasts thereof in the first few model time steps. Furthermore, the balancing procedure minimizes the time tendencies of the mass and wind fields at the lateral boundaries and thus provides a smooth start largely devoid of nonphysical gravity waves which characterize model runs initialized without some sort of equivalent procedure. The balance algorithm is described more fully in McGinley and Smart (2001). The adjustment in the third step often warms the cloud column so that some cloudy grid points become subsaturated. Thus, the fourth step is to re-set the relative humidity to 100% at such grid points. Failure to do so causes instantaneous evaporation, along with the associated cooling and subsequent false downdrafts, in the first few time steps (Cram et al. 1995).

The method has only been tested using MM5, but should be equally applicable in any model with explicit representation of cloud and precipitation processes. The correspondence between the water species as analyzed in LAPS and the hydrometeor fields in the forecast model have been worked out for the Schultz (1995) microphysics option, which is available in MM5, RAMS, and ARPS.

3. SUMMARY

Shaw et al. (2001b) give preliminary comments about the subjective quality of "hot-started" MM5 model runs provided in real time to the NWS forecast office in Boulder, CO. Shaw et al. (2001a) present objective verification of precipitation and cloud forecasts that show large improvements in skill scores over other initialization methods, especially in the first 6 h.

FSL has been running the diabatic initialization for MM5 model runs four times per day since late 2000. Plans for improving the system and implementing it in the Weather Research and Forecasting (WRF) model now under development are also given in Shaw et al. (2001a).

4. REFERENCES

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